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SOME SUGGESTIONS ON THE SAFE HANDLING OF ELECTRIC SHOVEL TRAILING CABLES IN OPEN-PIT MINES

BY

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DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

SOME SUGGESTIONS ON THE SAFE HANDLING OF ELECTRIC SHOVEL TRAILING CABLES IN OPEN-PIT MINES 1/

By F. S. Crawford 2/

The average visitor to a large electric-shovel operation may wonder how electric power can be treated as carelessly as apparently it is in open-pit mining, and how the mining company can string it carelessly along the ground in great, black, hoselike cables, whereas the power company, which has learned to respect this deadly agency, keeps power lines far out of reach. This is explained by the fact that this particular kind of application of power to moving machinery requires the use of a trailing cable instead of the more permanent type of construction that permits a moving contact, such as a trolley. The cables are designed to insulate fully the enclosed power lines against damage and loss of current; and employees are taught to handle them carefully, although engineers are not satisfied that the trailing cable is foolproof and are seeking constantly to improve methods and equipment to insure greater safety. In some sections they rely mainly on the construction of the cable and perfection of equipment, while in others additional precautions are taken, such as handling the cable with rubber gloves, slings, tongs, or loops. In some sections no temporary repairs are made to cables, while in others such repairs are made and later are vulcanized in the shop. At some operations the cycle of shovel duties is arranged so that cables are very seldom exposed to flying rock fragments while at others this exposure appears to be unavoidable. Methods of fastening the cable to the shovel frame and transporting the loose cable vary. Inspection and care of the cable are important in insuring its safety and durability.

A limited amount of information was obtained by field engineers of the United States Bureau of Mines from operators in various parts of the United States, as methods of handling electric-shovel operations differ with the districts; practices followed and equipment used in these districts are described in this circular.

ELECTRIC-SHOVEL OPERATIONS IN THE FLORIDA PHOSPHATE FIELD

Companies in the Florida phosphate field use dragline excavators with cables up to 1,000 feet long. At first these cables were attached to reels under the frame of the machine; however, considerable heating was experienced

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when the cable was kept on the cable reel and now it is strung on the ground or attached to the overhead lines at the top of power poles by means of a special "hot-stick" clamp. At one operation during the rainy season the cables are kept 1 or 2 feet above the ground, usually on notched 1 by 4's driven into the ground to keep tractors or persons from passing over the cable unintentionally. Three companies were using single-conductor cables testing for 2,300, 3,500, and 5,000 volts. One company was using a three-conductor cable with three small ground wires in the interstices between the insulated conductors. This company expressed a high opinion of the value of these three ground wires in case of break-down, as the current could more easily find a ground wire with less chance of injury to men handling the cable. Another company was using a four-conductor cable--three conductors for current and one for ground--insulated for 5,000 volts.

It is notable that although the service in this district is for 2,300 volts, cables rated at 5,000 volts are used to provide adequate insulation to protect the workmen.

At some operations the men handle the cables with rubber gloves, described in one instance as 10,000-volt linemen's rubber gloves with canvas protection. One company has established a penalty of discharge for infraction of the rule requiring the wearing of rubber gloves. A man using rubber gloves was disciplined but not discharged for putting the cable over his shoulder, the company suggesting that where more traction was required a well-paraffined rope sling be used to prevent passage of electric current.

Instead of rubber gloves some Florida companies provide a special "hot stick." Usually the power is turned off when the cable is to be moved to a new location, but in the few instances when it is moved with the power on this special "hot stick" is used. This is a round piece of second growth ash about 1-1/4 inches in diameter and 4 feet long, to one end of which is bolted a dull-pointed hook made of 1/2-inch round iron, flattened and drilled where it joins the handle. The stick resembles a shepherd's crook, and when used to move the cable when the power is on keeps the men at a fairly safe distance from the charged wires and obviates accidents in case the cable is damaged. The usual Florida practice is to use three-phase current at 2,300 volts.

Cables are inspected frequently by electricians and are discarded when the outer covering has become so cracked and deteriorated as to expose either ground or feed wires, even though megger (meg-ohm-meter) tests indicate the insulation is still in good condition. A cable showing insulation resistance of less than one meg-ohm is discarded if the location cannot be determined and the low point cleared. They also believe that an electrostatic ground detector is an important safety measure in the use of cables, since by this means grounds have been localized and the cable repaired before complete breakdown. A good ground is maintained also at each end of the cable.

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ELECTRIC-SHOVEL PRACTICE IN PENNSYLVANIA QUARRIES

The policy in some Pennsylvania quarries is to maintain short cable lengths from the shovels to permanent terminals because of the cost of the super-service cable required for this work. The cable from the shovel to the square-D switch on the permanent terminal varies in length from 100 to 150 feet. Permanent power lines are constructed to points adjacent to the working face of the quarry; a 550-volt current is transmitted over regular transmission lines on telegraph poles to a square-D switch with a load capacity of 100 amperes.

Temporary repairs are made to minor cuts and abrasions and bare wires are covered with rubberoid tape; when major defects occur the cable is spliced and then thoroughly insulated, the rubberoid tape used being acid-, water-, and alkali-proof.

Cables are exposed to damage from flying rock, especially when the cable is lying on the ground; therefore, cables are carried from the square-D switch on portable cross-arm "trees" to within a short distance of the shovel. The cable usually must lie on the ground for a short distance from the last support to the shovel.

A rigid regulation requires the use of rubber gloves (inside linemen's leather gauntlets) for handling the cable, as a slit in the insulation of the heavily-insulated superservice cable may not be immediately discernible and may thus create a hazard. An additional precaution in moving live cables is a rope sling 4 feet long, handled by two men, one on each side of the cable. As many slings are used as are necessary to handle the cable easily, especially when the shovel is being moved backward or forward, and care is taken not to drag the cable on the ground.

CENTRAL COAL FIELDS OF ILLINOIS, IOWA, AND INDIANA

Lengths of cable used in the central coal fields of Illinois, Iowa, and Indiana vary from 700 feet to 1,000 feet. Voltages used range from 300 to 5,000, kilovolt-ampere loads ranging from 500 to 1,500. At the operation using 300 volts a three-conductor cable was used with a single ground wire which was lugged and bolted at the shovel, while the other end was connected directly to the main power line with a clamp and "hot stick." The other operations, working with higher voltages and higher power, use a three-conductor cable with three ground wires between the conductors. The ground wires at one operation are connected together at each end and tied to a common ground bus. Although a number of companies use various sizes of ground wire within the cable, the total cross section of ground wires should be equivalent to a single phase conductor in current-carrying capacity. At some operations the ground conductors are connected directly to the frame of the shovel with the other end of the ground wires lugged solidly to the main ground system. In one instance the three-conductor cable with the three ground wires is covered entirely with tape and a woven copper-wire sheath grounded over the tape; this is followed with another tape covering over the ground wire sheath and a rubber jacket over all. The power wires are connected directly to the slip-ring assembly in the reel. One company that

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uses a cable with copper sheath has never had a fatal accident due to its cable or power system, although a man was shocked severely by a leaky cable that did not have a copper sheath.

According to one operator the cable should be connected to the junction boxes with plugged connections, with a stay insulated rod from the junction box pole connected to the trailing cable to relieve strain on the connection at the junction box; there should be two insulated junction boxes of metal and wood and two poles.

No mechanical method of fastening the cable to the shovel is required where cable reels are used, but a woven-wire cable grip is used with cable reels on small equipment. The cable should be clamped to the side of the shovel and enter through a bell-mouth insulator to protect it from being cramped in any position to which the shovel may move.

Reels on large equipment have proved highly satisfactory to some companies as the excess length of cable not in use can be rolled up and injury from flying rocks or trucks and other equipment prevented.

Cables for smaller equipment are allowed to be dragged along the ground sometimes. One company considers a reel impracticable because it would have to be attached to the tub; as the housing swings 360° the use of a reel appears to be impossible.

Various types of secondary connections are used in this field, such as a Y connection with solidly grounded neutral; one company using the Y connection establishes its own ground which is effectively connected to the ground on the power-transformer bank; a main power-distribution system consisting of a three-conductor, 5,000-volt, steel-wire, armored, main cable joined to the bus of a delta-connected Wye (Y) transformer bank, with three ground wires laid in the interstices, the total section of which equals that of one main conductor unbroken by switch, fuse, or other means and solidly connected to the neutral at the Wye (Y) bank.

Cables are inspected at frequent intervals at these operations. At some operations the cables are exposed to water frequently and in others not; in some places the water is acid and in others not.

One operator uses a special switch or junction house to which the trailing cables are connected. The ends of the cable terminate with high-voltage socket connectors attached to oil-circuit breakers, which are preceded by phase-opening devices operated simultaneously by a lever. Another operator has placed junction boxes at 1,000-foot intervals along the main distribution cable to provide taps for the various kinds of equipment. A tap is made through an oil circuit breaker to a set of fuse switches, thence to the load. If the load connection is to a shovel-trailing cable, the ground wires are connected solidly to the main cable ground without interruption. The metal junction boxes and the wire armor of the main cable are connected to the ground conductor.

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Temporary repairs are made in this field by using various kinds of rubber tape, rubber cement, and friction tape. One company uses rubber tape equivalent in dielectric strength and thickness to the original cable insulation, applied with a splicing compound to the original wall by approved rubber cement and covered by several layers of friction tape. With such care the trailing cables on shovels last from 6 to 8 years.

One company uses rubber cement and rubber tape covered with 1-1/2-inch green rubber friction tape and a trade preparation the life of the cable averaging about 4 years, depending on usage. Two companies vulcanize their cables in the shop, one using an electrically heated portable vulcanizing equipment and the other a steam portable machine.

At some operations cables frequently are exposed to damage from blasting and falling rock. Other hazards are exposure to the wheels of trucks; one company prohibits driving over cables.

Before handling or moving the cables one company disconnects them from the main cable by opening the oil-circuit breaker, except when lifting them over small obstructions, such as rocks, and uses a team hitched to the cable by a saddle made of a piece of split pipe bent to a semi-circle 24 inches in diameter. Some companies use both rubber gloves and tongs, others use insulated handled hooks and rubber gloves for emergencies. Metal hooks with rubber belting, slings, and cables are used for handling the cable with the shovel and bucket.

Several kinds of junction boxes are used; an oil switch with a disconnecting switch permanently connected in circuit is used for 2300 volts and a large heavy duty knife switch for 440 volts. At one operation a cast-iron junction box 11 inches square and 3 inches deep, with a cast-iron cover bolted in place, is mounted beneath the shovel. Junction boxes are not used to attach cables to the source of power; cable conductors are clamped to the power circuit near a steel tower, a man climbing the tower for this purpose; the power is cut off the main transmission line while this connection is being made. This operation uses power at 230, 480, and 5,000 volts. At another operation, the 2,300-volt caps are protected by overload coils; on 440-volt cables only the main circuits are protected by overload coils.

ELECTRIC SHOVEL PRACTICE IN WESTERN STATES

In the Western States cables used range in length from 400 to 1,000 feet; voltages range from 440 with a load of 300 kv-a to 5,000 with a load of 200 kv-a; one operation has 230 volts with 550 kv-a. Operators are using three-conductor power cables with three ground wires bolted either directly to the shovel at one end and to the ground system in the other end; or these three small strands are connected together for static balance without being connected to the shovel. The cable is fastened to the shovel frame by a large metal two-piece clamp so that essentially no strain comes on the electrical connections, or a wooden cleat is used on the cable.

Repairs to cables are made with rubber friction tape, rubberoid, or 1-inch vulcanizing tape. The average life of the cable varies from 6 months

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to 2 years for a fabric to 4 years for a rubber-covered cable; at an operation that makes permanent repairs in the field one rubber-covered cable has been in use since 1923. Some companies make numerous tape repairs before taking the cables to a shop for vulcanizing. Electric vulcanizing machines or steam vulcanizers, heated by electricity, are used; although these machines are portable, all the vulcanizing is done in the shop as it is considered impracticable and a waste of time during continuous operation to vulcanize in the pit.

At all operations in the Western States from which information was obtained, cables are exposed to danger from blasting at all times as well as danger from truck wheels and caterpillar treads. One operation attempts to eliminate this hazard by supporting the cable overhead on tripods.

Large trailing cables are handled by tongs and hooks. The hooks are about 30 inches over all and consist of a shovel handle with a steel hook instead of the shovel. The tongs are about 4 feet long and sometimes a dozen or more are carried on each shovel. The cable is picked up in 25- to 30-foot loops, each loop being held by one set of tongs on a bar at the back of the shovel, until several loops are dragging behind the shovel; these loops are dragged over sharp rocks and rough ground. Reels are used at some operations while at others the size of the reel prohibits its use as it restricts the shovel-digging operation to considerably less than 360°.

The delta and Y types of secondary connection are used in the West. In one instance shovels with motor generator sets using 5 kv-a had motors and no transformers.

Cable inspections are supposed to be made every day, especially when the cable is covered with water for a considerable period, as the water is acid.

ELECTRIC SHOVEL OPERATIONS IN LAKE SUPERIOR DISTRICT

Lake Superior iron-mine operators use cables from 1,000 to 5,000 feet in length. The long cables are necessary to allow a shovel to move from one part of the pit to another when necessary to load different grades of ore. Voltages are variable—2,300 to 4,000 volts, with 440 volts used on small operations. The load also ranges from 150 to 1,500 kv-a.

Various types of cables are utilized. One company uses the three-conductor cable with one ground wire; another uses a three-conductor cable with three small strands as a ground in the interstices between the conductors, and a basket weave of copper wires on the outside of each conductor but inside the three ground wires, the ground wires coming directly in contact with the basket weave. The basket weave around each conductor serves as a shield against the corona effect that breaks down the insulation between conductors and also serves as additional protection to workmen. A solid mechanical connection for these ground wires is made at the shovel and no junction box is used.

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One company uses two types of cable, both having woven ground braid over each conductor, one cable having three small strands in the interstices as well as woven ground braid over each conductor, while the other cable does not have the three extra small strands, but has a braided copper sheath around each insulated conductor, the sheath being deemed necessary for the protection of men handling the cable. The latter cable also has an additional definite ground conductor, in some cases the ground conductor being three small additional strands or an equivalent single larger wire. Where the ground connection is made at the shovel the ground conductors are bunched and lugged to the shovel frame. This company is studying the feasibility of installing a reactance in the ground connections to limit the current flow in the case of an accidental contact to ground.

It is noted that in this district, where probably more shovels are used than in any other part of the country, a braided ground sheath is favored by virtually all companies, some preferring the ground sheath around all three conductors and others around each conductor separately. Portable switch houses are used quite generally also.

It is the general practice to use some kind of clamp around the cable, attaching it to the shovel by chains or steel cables. Such clamps usually have wood and woven-wire grips, one type being described as a universal double-eye cap switch.

One company uses an oil circuit breaker inside the shovel cab. Another company has feeder-station switch houses with an oil circuit breaker enclosed for each cable to each shovel; the overhead lines run to the edge of the pit; the connections are then made through the shovel switch house with oil-circuit breakers, disconnecting switches, and overload relays for full protection, the oil circuit breakers being supplied by several companies.

Most of the companies make temporary repairs in the field without sending the cable to the shop. One company uses a tape of semicured noncorrosive rubber. Another company makes very thorough field repairs; the fault in the line is located, the cable conductors are laid bare, and the electrical connection is made; the conductors are then taped properly and covered with a pipe sleeve mechanical joint, which is sealed on each end with rubber glands. After a number of these mechanical connections have been made the cable is taken into the shops for vulcanizing. In another operation a splice is made with soldered connectors, then the conductor is penciled and wrapped with rubber tape until the insulation is as thick as the original insulation; the insulation is then rewrapped, bound with copper wire, the end of the jacket rubber penciled, and built up with rubber tape to the thickness of the jacket; the surface of the splice and well up on the jacket is then covered with friction tape and painted with all-dry insulating paint. Cuts in the jacket alone are cleaned out and filled with plastic rubber friction tape and paint. One company uses 40 percent semicured rubber tape, and friction tape for temporary repairs; it has a manual showing the types of repairs to be made at its operations. Badly cut cables of all companies are taken to the shops for vulcanizing.

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The life of cables in the Lake Superior district is comparatively long; the length of life is rather uncertain, however, as more cables are scrapped because they are obsolete than because they have worn out. The minimum life is 5 years although one company has had a cable in use for 11 years. Cables have been scrapped sooner owing to chemical corrosion of the braided copper sheath; if such corrosion could be eliminated, perhaps by changing the rubber insulating compound, the average life probably would be at least 10 years. Chemical corrosion applies particularly to the braided copper sheath around each insulated conductor, and probably is caused largely by the sulphur used in the curing of the rubber. The comparatively long life of the cables in this district is due to the general practice of carrying the cables behind the shovels on a drag or boat instead of dragging them, which reduces the wear from abrasion.

In some of the open-pit mines the cables frequently are exposed to damage from flying rocks from blasting, in others they are seldom exposed to blasting. Sometimes the cables are damaged by rocks that roll down the pile, and they are not protected from blasting by bulldozing. As a rule, the major blasting operations are carried on in one part of the pit while the shovel is working in an entirely different part. At one operation the cables suffered considerable damage in passing under tracks without protection, so a split-pipe trough was made of a 6-inch pipe 8 feet long through which the cable was passed under the tracks.

The general practice is to use few or no trucks in the open-pit mines. In one operation the cable is protected with planking on both sides when it is necessary for a shovel to go over it, as the electric shovels run on caterpillar treads.

Large trailing cables generally are handled with bare hands not even protected with rubber gloves, the braided copper sheath on each conductor being considered as complete protection against shock from handling the cable; this braided copper sheath is grounded and serves as a ground return. It is not considered safe, however, to dispense with protective devices in handling the ordinary cable with three small separate wires as a ground without the copper sheath around each conductor, and some companies handle the cable with loose loops and use rubber gloves, but these companies are very much in the minority. One of these companies is experimenting with the use of tongs, but has not tried them long enough to recommend them. The usual practice is to carry the excess cable in figure-8 loops on a drag or cable boat behind the shovel. Reels appear to be satisfactory on the large stripping shovels but not on the smaller machines.

The delta with ungrounded neutral is the most favored secondary connection although several large operators use the Y connection grounded with a solid neutral.

Visual inspection is made for cuts and abrasions for the full length of the cable. Some companies inspect cables at frequent intervals, while others inspect only at the beginning of the operating season. Both visual and electrical methods are used. It appears, however, that the most durable cables

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are those frequently inspected and tested. One company tests the cables by putting more power on them than is used in service; this is done with a special testing set when a fault occurs in the line. Afterward the testing is done periodically, the same set being used for testing the continuity of the ground circuit. One company examines the full length of cable for breaks in the rubber and turns high voltage--5,000 volts where ordinarily 2,300 volts are used--on the line and tests the ground for load carrying. Another company tests for the resistance and continuity of the ground conductor after having made the visual inspection for external damage. The voltameter is used for resistance testing and the megger (meg-ohm-meter) for insulation.

Most open-pit mines contain considerable water at times, but the water is not acid; the cables, of course, are taken out of water as soon as possible, but they may lie under water for several hours or days. An electrical engineer stated that it would not matter if the water were acidic as the insulation is so well made the cable would not be affected.

One of the larger operators in the Lake Superior district has used electric shovels in open-pit mines on the Mesabi Range in Minnesota since 1926 and found them superior to the steam shovel from a safety standpoint. Up to 1935 this company had never had a fatal accident due to faulty electric-shovel equipment, although there had been two fatalities due to bad practices, which were violations of already existing safety orders of the company. In one instance a fatal underground mine accident occurred when a miner carrying a drill steel over his shoulder contacted a trolley wire with the steel at a point where the trolley wire was guarded by side boards. Another accident due to faulty practice occurred when the electricians repairing an electric shovel in an open-pit mine went to the wrong switch house to shut off the power before making repairs; the man on the shovel was killed by coming in contact with conductors he supposed were dead. Future accidents from this cause have been guarded against by having a separate switch house for each shovel with a different lock on each switch house, and the only key to the house, properly tagged, in the hands of the shovel runner. Electricians must go to the shovel runner to get this key before they can work on the lines to his shovel.

The conditions under which shovels operate in the open-pit mines of the Lake Superior region are quite severe, since the shovels must go to all parts of the pit on various levels in order to get to the grade of ore wanted. Ordinarily it is not possible to keep a shovel working continuously on one bank; consequently it is necessary to handle the cable frequently. The cable, however, is not dragged, and most of it is carried on cable boats.

The electric-shovel trailing-cable installations at Lake Superior operations are in the process of change. An important feature now being developed is a system of grounds and ground wire reactances designed to cut down the flow of electric current in the ground connection in case the frame of any shovel or any other equipment in the pit should become charged accidentally. Then, if such a short circuit should occur, a current of only 10 amperes would flow through the ground circuit from the shovel frame to the feeder

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station or circuit breakers for only 1/2 second and blow out that circuit breaker. The reactance for each shovel is thus designed for almost instantaneous tripping in case of a short circuit to ground. A second reactance in each of the three main power wires of the Y-connected system at the substation limits current flow to 50 amperes for 1-1/2 seconds, and operates as a delayed tripping device in case the instantaneous tripping at the individual shovel switch house fails. The system being worked up by the engineers is designed for the primary purpose of preventing accidental injuries to the workmen due to short circuits from electrical machinery on shovels to the frame of the shovel.

SUMMARY

Safe handling of electric shovel-trailing cables appears to be largely a matter of good equipment together with care in keeping cables in repair and protecting them from injury. The best way to protect men handling cables against electric shock seems to be to include a woven-wire sheath on the outside of the conductors, opinion being divided as to whether the sheath should be over each one separately or on the outside of all three. An additional protection is the three small ground wires that make contact with the woven ground wire sheath.

Even with the best cable equipment and most careful handling, there is always the hazard that the shovel frame may become charged and that anyone stepping onto it might receive a shock. It is hoped that the electrical engineers working on this problem will be able to solve it. When they do, there is no doubt that public-spirited corporations employing such engineers will pass on to the industry the results of their work on the problem of making electrical operations safer for the man on the shovel.

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